IOP Conference Series: Earth and Environmental Science

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To cite this article: M Saleh *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **623** 012021

Technology and economic analysis of urban waste potential (case study of Jatibarang landfill)

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Abstract. The high volume of waste produced by both industry and society is common in almost all cities. For this reason, it is necessary to control the increase in the volume of waste and its implications for the environment. The scenario used in this research is to design a power plant that can be used to control the increase in the volume of waste, namely PLTSa (Waste Power Plant). PLTSa uses organic waste from trash to generate clean, renewable energy, powering communities, and reducing emissions. At the PLTSa, the organic waste is fed into a digester tank, where it is converted into methane by bacteria. The gas is then sent to the waste power plant, which generates 0.9 MW of power. The PLTSa supports the Indonesian government's plan to increase electricity in the country by 35,000 MW from 2015 to 2019, and for 25% of that electricity to be generated from renewable sources. The government's plan was in response to a shortage of electricity generation capacity as demand in the country grows. The data analysis method used to analyze the research data is an analysis using the IPCC Inventory software and the LFGcost-Web Landfill Gas Emission Model (LandGEM). Data analysis results in the form of projections of biogas potential and electrical energy will be used to build PLTSa. Waste-to-energy generation is being increasingly looked at as a potential energy diversification strategy, especially in Indonesia and PLTSa (Waste Power Plants) in several cities in Indonesia.

1. Introduction

One of the real consequences of population growth and the rapid increase in big cities' activities is the increasing amount of waste. In Indonesian cities, the main paradigm in waste handling has been collection-transport-disposal. As the population grows, the amount of waste that must be handled will increase as well [1].

One of the programs expected to solve the waste problem in cities is waste-to-energy plant. Organic waste will decompose anaerobically and produce landfill gas (LFG). Landfill gas from anaerobic fermentation process of organic materials will increase the landfill temperature, causing unpleasant odor and even may cause an explosion. However, if methane in landfill gas is managed well, it can be beneficial, such as in reducing the greenhouse effect and environmental damage. It can even be used as the fuel for waste-to-energy plant. A waste-to-energy plant is a waste management facility that combusts wastes to produce electricity. This type of power plant is sometimes called a trash-to-energy, municipal waste incineration, energy recovery, or resource recovery plant. This waste-to-energy management is Indonesia's commitment to reducing carbon emission according to the agreement of Paris Conference (COP21) at the end of 2015. In regards to waste-to-energy plant regulation, it has been stated in Presidential Decree No. 18 in 2016 concerning the Acceleration of Waste-based Power Plant Development. The decree names seven cities as the pilot projects: Jakarta, Tangerang, Bandung, Semarang, Surakarta, Surabaya, and Makassar [2]. Based on that point of view, the conversion of municipal solid waste to energy has a great potential in reducing the volume of waste and increasing the production of alternative fuel as well as reducing carbon emission.

2. Methodology

2.1. The municipal solid waste

The Municipal Solid Waste (MSW) Initiative aims to enable cities to develop robust waste management systems to achieve real and immediate SLCP reductions and other development benefits. In Indonesia, the common waste categorizations are organic or wet waste, consisting of leaves, woods, forage leftovers, vegetables, fruits, etc. The inorganic or dry waste consists of cans, plastic, iron and other metals, glass, and mica. Waste can decompose in two ways: biochemically and physically [3].

Table 1. Calorific value based on the types of waste.

No	Type of waste	Percentage (%)	Calorific value (MJ/Kg)	Total calorific value (MJ/Ton)
1	Leaf	17	5.7	969
2	Vegetables and fruits	43	14.2	6,106
3	Paper	3	15.6	468
4	Textile	5	36.8	1,840
5	Excrement	12	6.9	828
6	Etc.	2	18.1	362
	Total Calorific Value		82	10,573

Table 2. Projected waste tonnage for the next 5 years.

Year	Waste/day
2020	675
2021	750
2022	775
2023	800
2024	850
2025	890

2.2. Landfill gas (LFG)

Landfill Gas is a gas produced from a biology decomposition reaction process where organic matters are converted into CO_2, CH_2, ammonia, and hydrogen sulfide. The decomposition will continue aerobically in a short time until the available oxygen lessens. Bantargebang waste processing plant (or TPST in Indonesian) produces an average of 6,000-7,000 tons/day of waste [6]. The percentage of constituent gas of LFG can be seen in table 3.

IOP Conf. Series: Earth and Environmental Science **623** (2021) 012021 doi:10.1088/1755-1315/623/1/012021

Table 3. Constituent gas LFG [7].

Constituent Gas of LFG	Chemical Formula	Percentage (%)
Methane	CH_4	50-70
Carbon dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2
Nitrous oxide	N_2O	0.3
Hydrogen Sulfide	H_2S	Very little

That 1 Kg of methane gas is equivalent to 6.13 x 10^7 J, while 1 kWh is equivalent to 3.6 x 10^7 Joule. The density of methane gas is 0.656 kg/m^3 so that 1 m^3 of methane gas produces electrical energy of 11.17 kWh. Conversion from methane to electricity according to table 2 for the 5 next year will be calculated below:

2.2.1. Energy production in biogas is proportional to methane gas production (2020). With a known biogas production value (VBS) of 675 m^3 /day and from table 1, it can be seen that the production of methane gas (VGM) is 50% in 2020:

- VGM = 50% x VBS
  = 50% x 675 m^3/day
  = 337.5 m^3/day
- Calculation of the potential for electrical energy produced:
  E = VGM x FK
  = 337.5 m^3 x 11.17 kWh
  = 3,769.875 kWh/day
- The power generated by the Biogas Power Plant is the energy generated per day divided by 24 hours, namely:
  P = E/24
  = 3,765.875/24
  = 157.07 kW ≈ 0.157 MW
- The selling price of electric power to PT.PLN
  Selling Price = 3,769.875 kWh/day x Rp1.100.-
  = Rp4.146.862,5.-/day

2.2.2. Energy production in biogas is proportional to methane gas production (2021). With a known biogas production value (VBS) of 750 m^3 /day and from table 1, it can be seen that the production of methane gas (VGM) is 50% in 2021:

- VGM = 50% x VBS
  = 50% x 750 m^3/day
  = 375 m^3 /day
- Calculation of the potential for electrical energy produced
  E = VGM x FK
  = 375 m^3 x 11.17 kWh
  = 4,188.75 kWh/day
- The power generated by the Biogas Power Plant is the energy generated per day divided by 24 hours, namely:
  P = E/24
  = 4,188.75/24
  = 174.53 kW ≈ 0.174 MW

- The selling price of electric power to PT.PLN
  Selling Price = 4,188.75 kWh/day x Rp1.100.-
  = Rp4.607.625,-/day

2.2.3. Energy production in biogas is proportional to methane gas production (2022). With a known biogas production value (VBS) of 775 m^3 /day and from table 1, it can be seen that the production of methane gas (VGM) is 50% in 2022:

- VGM = 50% x VBS
  = 50% x 775 m^3/day
  = 387.5 m^3 /day
- Calculation of the potential for electrical energy produced
  E = VGM x FK
  = 387.5 m^3 x 11.17 kWh
  = 4,328.375 kWh/day
- The power generated by the Biogas Power Plant is the energy generated per day divided by 24 hours, namely:
  P = E/24
  = 4,328.375/24
  = 180.348 kW ≈ 0.181 MW
- The selling price of electric power to PT.PLN
  Selling Price = 4,328.375 kWh/day x Rp. 1.100
  = Rp.4.761.212,-/day

2.2.4. Energy production in biogas is proportional to methane gas production (2023). With a known biogas production value (VBS) of 800 m^3 /day and from table 1, it can be seen that the production of methane gas (VGM) is 50% in 2023 :

- VGM = 50% x VBS
  = 50% x 800 m^3/day
  = 400 m^3 /day
- Calculation of the potential for electrical energy produced
  E = VGM x FK
  = 400 m^3 x 11.17 kWh
  = 4,468 kWh/day
- The power generated by the Biogas Power Plant is the energy generated per day divided by 24 hours, namely:
  P = E/24
  = 4,468/24
  = 186.16 kW ≈ 0.186 MW
- The selling price of electric power to PT. PLN
  Selling Price = 4,468 kWh/day x Rp1.100.-
  = Rp4.914.800,-/day

3. Results and discussion
Using the data from the calculation, it can be concluded that a power plant can be designed and built-in Jatibarang landfill to reduce the volume of waste. The designed waste-to-energy plant can be a renewable power generator.

3.1. Waste-to-energy plant system
A power plant commonly consists of a turbine and electric generator. Turbine is used as a tool to rotate the electric generator's rotor and the rotation produces electric power. Electricity generation system that changes natural energy to mechanical energy, which then becomes electric energy can be categorized based on its fuel [8].

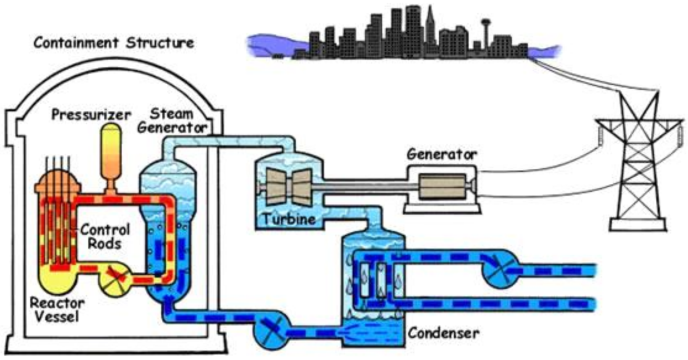

Figure 1. Steam-electric power station.

Waste-to-energy plant uses landfill gas from waste decomposition. Its methane gas is then used as a generator (gas engine) fuel, generating electricity. Aside from that, the gas engine itself which was broken needs to be fixed by having its spare part installed and applying continued maintenance to minimalize future damages.

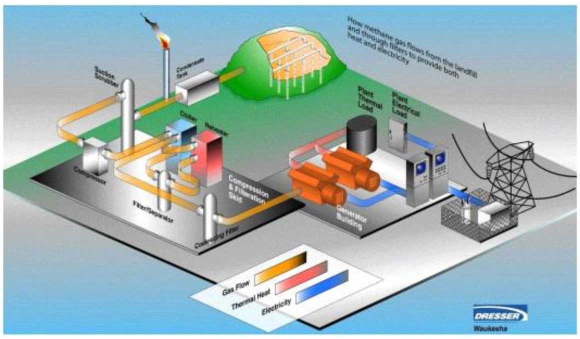

Figure 2. The project of LFG utilization as a power plant.

In the project in figure 2, there are several treatments for waste to produce gas, which will be used as a material for power plants. The gas produced by landfill (LFG) through anaerobic process is then caught in a gas well and helped bring to the surface using a blower. Other than gas, the output of that process is leachate. With geomembrane layer in the landfill, the leachate will not pollute the soil or groundwater. The leachate will flow to the evaporator through the pipes that have been provided [9].

3.2. Electricity generation

3.2.1. Turbine gas engine. A turbine gas engine is a device that uses gas as the fluid to rotate the turbine with internal combustion. Inside the gas turbine, kinetic energy is converted into mechanical energy through pressured air, which rotates the turbine wheel to produce power. The most straightforward gas turbine system consists of three components: compressor, combustion chamber, and gas turbine. Gas turbine acts as the prime mover to rotate the generator to produce electricity. Unlike a combustion engine, in a gas turbine, the heat resulting from burning LFG is used to rotate the turbine. The turbine is coupled with a generator to produce electrical energy for the load. The exhaust heat from the turbine is reused by the recuperator, and the exhaust heat recovery for various purposes.

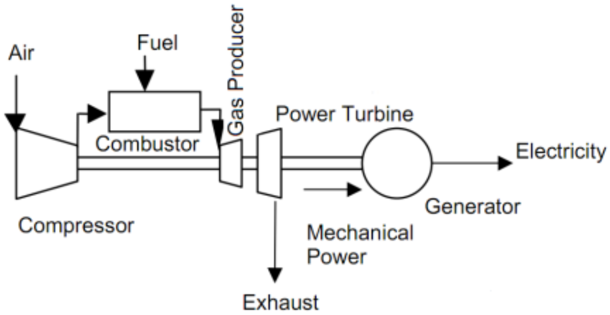

Figure 3. Turbine gas engine.

In general, the gas turbine in a landfill has the following basic components:

A. *Compressor*
The compressor takes the air from the outside and then solidifies and compresses the air molecules by rotating and stationing the compressor's blades.

B. *Combustor*
In the combustor, the fuel is added to the compressed and burned air molecules. Heated molecules will expand and rapidly move towards the turbine.

C. *Turbine*
The turbine converts the energy from high-speed gas to rotational power on turbine rotor blades.

D. *Output shaft and gearbox*
Rotational power on the turbine will be brought to the moving device through the gearbox's output shaft.

E. *Exhaust*
The exhaust will direct the exhaust gas from the turbine to the atmosphere. The sizes of gas turbine may vary from 1 MW to 100 MW. This advancement in technology results in a significant reduction, both in installation cost and the emission. The fuels that can be used are natural gas, oil and fuel gas produced from conversion processes such as coal gasification or gasification result through pyrolysis or anaerobic digestion of biomass. Gas turbine will then be coupled to a generator mechanism to produce electrical energy.

3.2.2. Generator. An electrical generator is a device that produces electrical energy from a mechanical energy source. This process is known as electricity generation. This mechanical energy can be obtained from the process in the gas turbine, steam engine turbine, the water that falls through a turbine or a water mill, internal combustion engine, wind turbine, hand cranks, sun or solar energy, compressed air, or the other mechanical energy sources. Next, this mechanical energy will be passed on to the generator shaft to rotate the generator rotor and produce electrical power. Nowadays, a generator product is an integral part of a prime mover. Selecting a generator is determined by the type of prime mover fuel and technical specifications, such as capacity, frequency, and desired voltage. Apart from that, many generators have become one with the engine-generator. Consequently, with such technological advancement, the generator engine can become one with a power generation engine.

4. Conclusion

The tendency of waste-to-energy plant utilization in a developed country in general is still under the percentage of managing by reclamation. Choosing to use waste-to-energy plant depends on the type of waste being burned to optimize the utilization. Waste-to-energy plant is not better than the other gasification methods such as plasma.

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